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Canadian Science Advisory Secretariat
Science Advisory Report 2009/005

2007 STATE OF THE OCEAN: CHEMICAL AND BIOLOGICAL OCEANOGRAPHIC CONDITIONS IN THE GULF OF MAINE - BAY OF FUNDY AND ON THE SCOTIAN SHELF

Figure 1. AZMP-Maritimes fixed stations and shelf sections.

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The AZMP uses data collected through a network of sampling locations (fixed point stations, cross-shelf sections, trawl surveys, satellite remote-sensing) in Quebec, Maritimes, Southern Gulf, and Newfoundland sampled from bi-weekly to annually. Information on the relative abundance and community structure of plankton is also collected from Iceland to the coast of Newfoundland and Newfoundland to the Gulf of Maine through commercial ship traffic instrumented with a Continuous Plankton Recorder (CPR).

A description of the distribution in time and space of nutrients dissolved in seawater (nitrate, silicate, phosphate) and oxygen content provides important information on the water movements and on the locations, timing and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine food-web. An understanding of the production cycles of plankton is an essential part of an ecosystems approach to fisheries management.

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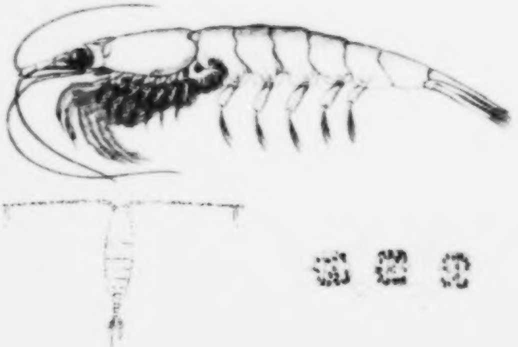

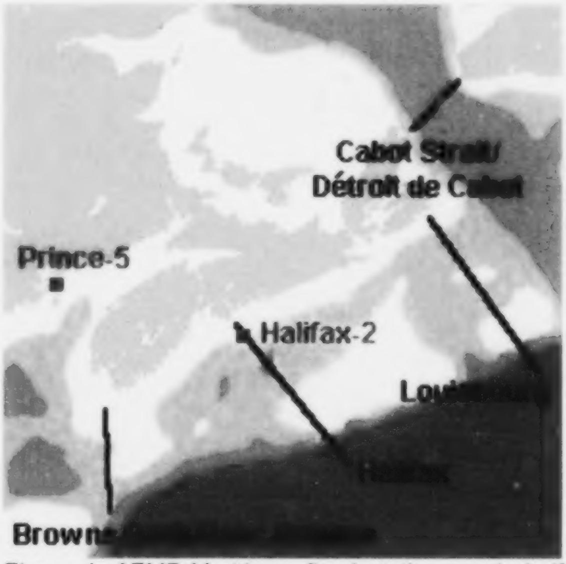

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SUMMARY

- Winter nutrient levels at Halifax-2 were normal in 2007 while winter levels at Prince-5 were higher than usual.
- Deep nutrient inventories (50-150 m) in spring were low, shelf-wide.The summer nutrient inventories and the depth of nutrient depletion at Halifax-2 and Prince-5 in 2007 were among the lowest (deepest) seen since observations began in 1999.The spring phytoplankton bloom was at record high levels over the entire Scotian Shelf in April 2007.
- Chlorophyll levels outside of the bloom period have been declining since observations began in 1999.
- Zooplankton biomass and abundance were low in 2007, but there were near-record peaks in zooplankton biomass and *C. finmarchicus* abundance at Halifax-2.
- Warm-water zooplankton taxa that are usually abundant during summer and fall were less abundant than normal on the Scotian Shelf, and Arctic species made up a larger proportion of the community than normal on the eastern Scotian Shelf.
- At Prince-5, species that are normally dominant were not abundant, and cladocerans were abundant.
- Observations from the Continuous Plankton Recorder indicate that, compared with the historical data record (starting in 1961), current phytoplankton and zooplankton abundances on the Scotian Shelf are close to the long term average.

INTRODUCTION/BACKGROUND

The production cycle of plankton is largely under the control of physical processes. Specifically, light and nutrients (e.g. nitrate, phosphate, silicate) are required for the growth of marine microscopic plants (phytoplankton). Of the major available nutrients, nitrogen is generally in shortest supply in coastal waters and is thought to limit the growth of phytoplankton, particularly in summer. A description of the cycle of nutrients on the continental shelf will aid in understanding and predicting the spatial and temporal variability in plankton populations.

Phytoplankton are the base of the marine food-web and the primary food source for the animal component of the plankton (zooplankton). Both phytoplankton and zooplankton, in turn, are food for larval fish and invertebrates and influence their survival rate. An understanding of plankton cycles will aid in assessing the state of the marine ecosystem and its capacity to sustain harvestable fisheries.

The AZMP provides basic information on the natural variability of physical, chemical and biological properties of the Northwest Atlantic continental shelf. Ecosystem trawl (groundfish) surveys and cross-shelf sections provide detailed regional geographic information but are limited in their seasonal coverage. Critically placed fixed stations (Station 2 along the Halifax section on the Scotian Shelf and the Prince 5 station in the Bay of Fundy) complement the geography-based sampling by providing more detailed information on seasonal changes in ecosystem properties. Satellite remote-sensing of sea-surface phytoplankton biomass (chlorophyll) provides a large scale, zonal, perspective on important environmental and ecosystem variability. The CPR sections provide information on large scale, inter-regional, and long-term (yearly to decadal) variability in plankton abundance and community structure.

ASSESSMENT / ANALYSIS

Nutrients

Fixed Stations: Distributions of the primary dissolved inorganic nutrients (nitrate, silicate, phosphate) included in the observational program of AZMP strongly co-vary in space and time (Petrie et al. 1999). For that reason and because the availability of nitrogen is most likely to limit phytoplankton growth in our coastal waters (DFO, 2000), emphasis in this report will be placed on variability in nitrate concentrations.

Rapid spring/early summer reduction in near surface nitrate concentrations was seen at both Maritimes fixed stations in 2007 (Fig. 2). Low surface values persisted throughout the summer/fall at Halifax-2; concentrations did not increase at the surface again until late fall. The zone of nitrate depletion (i.e. defined as depths where concentrations were $\leq$1 mmol m^{-3}) in summer 2007 at Halifax-2 (38 m) was close to the record depths observed in 2004 and 2005 (>40 m) and deeper than the long-term average (34 m). The seasonal evolution of the vertical nitrate structure at Halifax-2 in 2007 was similar to that observed in previous years. Anomaly plots showed that nitrate concentrations in surface waters were near normal and in deep waters (>50 m) somewhat lower (-2 to -4 mmol m^{-3}) than the long term average. Near surface nitrate concentrations at Prince-5 in 2007 were seldom reduced below 2 mmol m^{-3}. Anomaly plots for this station indicated that nitrate concentrations were higher (>2 mmol m^{-3}) than usual in winter, and variable (±2 mmol m^{-3}) in surface and deep waters the rest of the year.

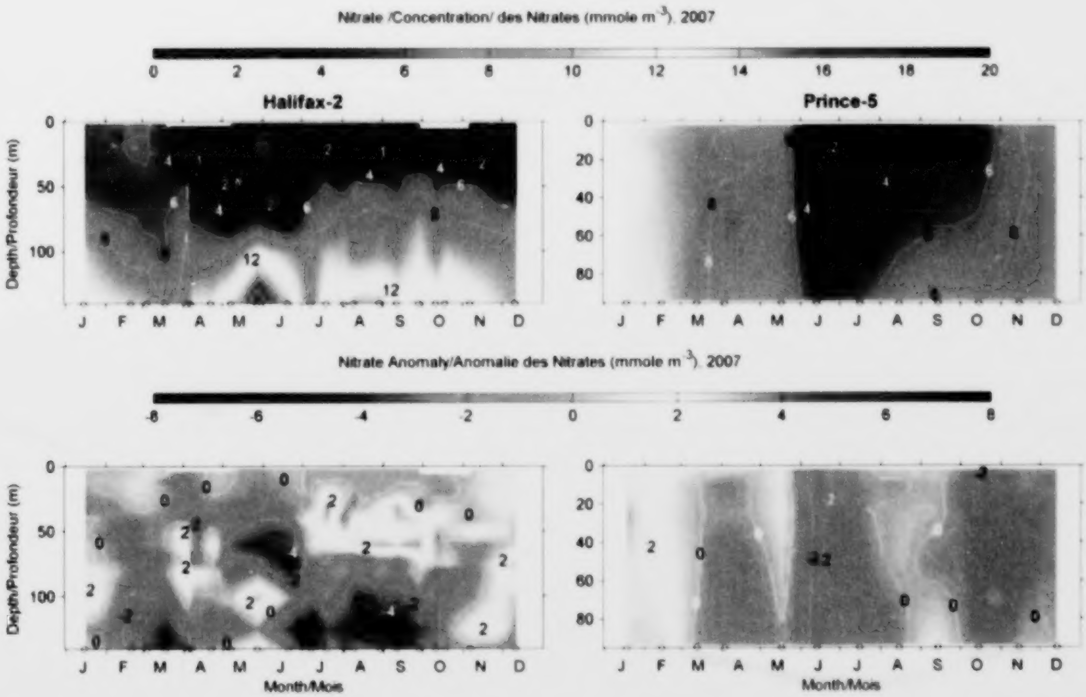

Figure 2. Vertical nitrate structure and nitrate anomalies (2007 minus long-term mean) at the AZMP-Maritime fixed stations in 2007.

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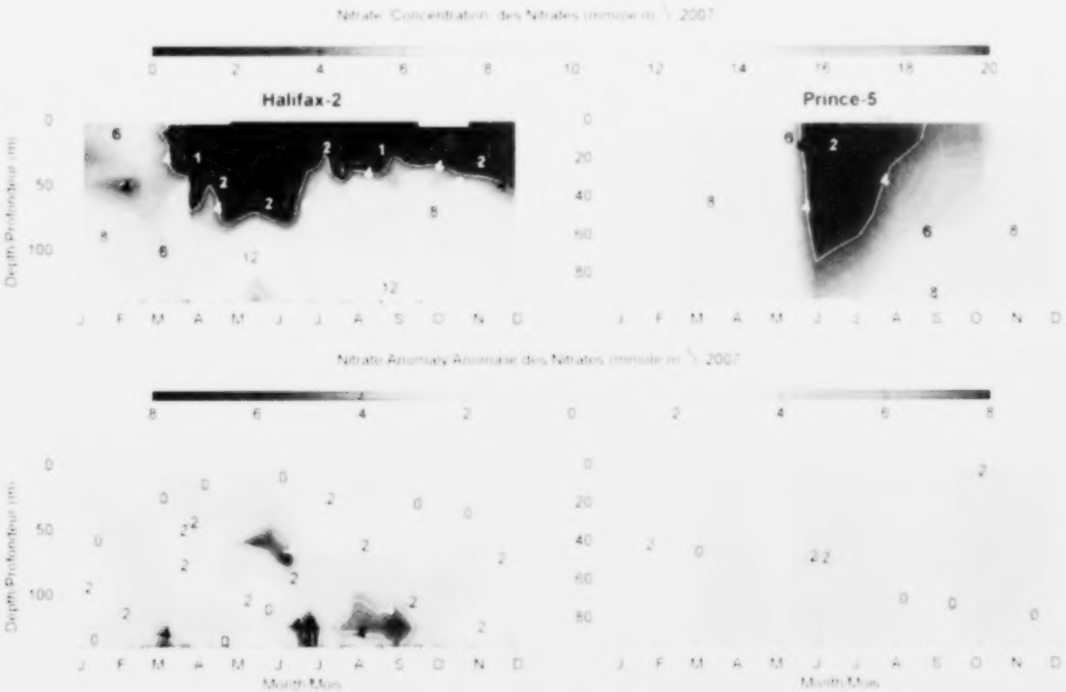

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Strong seasonal variability in nitrate inventories of the upper 50 m (depth zone over which nutrient dynamics are strongly influenced by biological processes) is evident at both of the Maritimes fixed stations (Fig. 3). Although the seasonal pattern of variability in nitrate at Halifax-2 in 2007 was similar to that observed in previous years, inventories immediately following the spring bloom were lower (~20 mmol m^{-2}) than seen in the previous years. Winter maximum nitrate inventories in the upper 50 m at Prince-5 in 2007 (~560 mmol m^{-2}) were significantly higher than the long term average (~470 mmol m^{-2}) but, like Halifax-2, summer levels (~100 mmol m^{-2}) were lower than the norm (~210 mmol m^{-2}). Nitrate inventories in deep waters (>50 m; data not shown) at Halifax-2 in 2007 were generally comparable with the long-term average (~700-900 mmol m^{-2}). At Prince-5 nitrate inventories in deep waters in 2007 were higher in winter (~500 mmol m^{-2}) and lower in summer (~180 mmol m^{-2}) than the long-term mean (winter: ~420 mmol m^{-2}, summer: ~270 mmol m^{-2}).

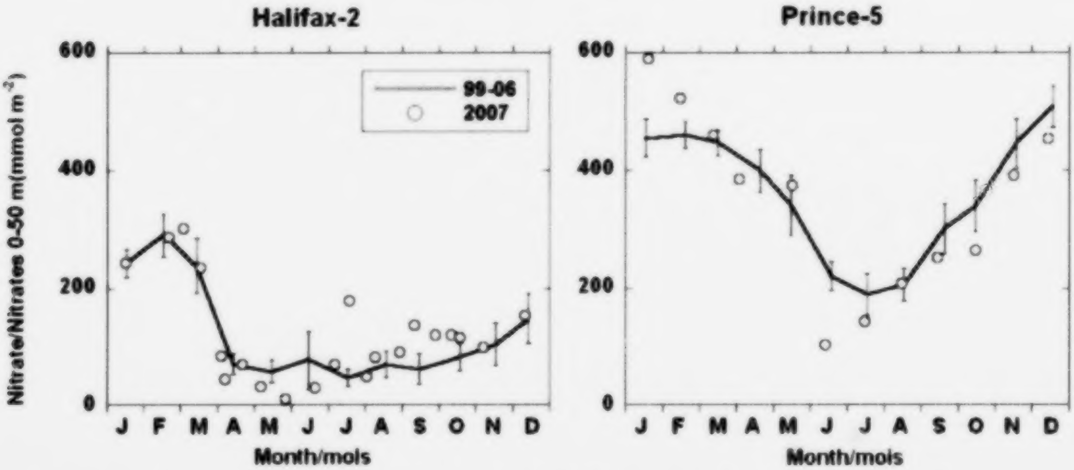

Figure 3. Nitrate inventories (surface to 50 m) at the AZMP-Maritimes fixed stations in 2007.

Shelf Sections: Vertical distributions of nitrate in spring were generally similar along the Scotian Shelf sections in 2007, i.e. concentrations were low (<1 mmol m^{-3}) in near surface waters (<50 m), as a result of phytoplankton consumption, and increased with depth; the exception was along the Cabot Strait line where surface concentrations generally exceeded 2 mmol m^{-3}. Deep-water concentrations were highest in basins (>20 mmol m^{-3}) and in slope waters off the edge of the shelf. As in previous years, nitrate levels in surface waters were already reduced at the time of the spring survey (4-22 April) to values approaching 1 mmol m^{-3} depth horizon: ~20-50 m. Likewise, surface nitrate concentrations were still low during the fall survey in October (1 mmol m^{-3} depth horizon: ~20-50 m), showing no evidence of seasonal mixing of nutrients from depth into surface waters. Nitrate inventories in the upper 50 m in 2007 were comparable to levels observed in previous years in fall, however, record high levels (Avg: ~140 mmol m^{-2}) were seen along the Cabot Strait line and record low levels (Avg: ~50 mmol m^{-2}) along the Browns Bank line in spring. On both the Louisbourg and Halifax lines, there is a trend of increasing inventories over time in both spring and fall whereas there is a decreasing trend on the Browns Bank line. Deep nitrate inventories (50-150 m) were lower (480-600 mmol m^{-3}) than normal (570-740 mmol m^{-3}) in spring but comparable to levels seen in previous years in fall, 2007; there is a suggestion of a small but general decline in inventories over time, particularly in spring.

Trawl (groundfish) Surveys: Bottom water nitrate concentrations on the Scotian Shelf in July 2007 (Avg: 9.6 mmol m^{-3}) were the lowest on record, long-term average = 11.6 mmol m^{-3}. Concentrations increased with water depth with highest levels observed in the deep basins on

the shelf (e.g. Emerald Basin) and in slope waters off the shelf edge. Bottom water oxygen saturation on the Scotian Shelf in summer 2007 (Avg: 77% sat), in contrast, was similar to the long-term average (79% sat). Similarly, the area of the bottom covered by waters with <60% saturation was the same as the long term average (16,600 km^2 or ~11% of the shelf area. Lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest.

Phytoplankton

Fixed Stations: Distinctly different seasonal phytoplankton growth cycles are evident at the two Maritimes fixed stations (figs. 4 and 5). The strongest (magnitude) spring bloom on record (976 mg m^{-2}) was observed at Halifax-2 in 2007 (Fig. 5), considerably higher than the long term average (436 mg m^{-2}) and in marked contrast to the record low seen in 2006 (256 mg m^{-2}). Anomaly plots suggested that the timing of the 2007 spring bloom was consistent with the long term mean (peak at YD 97) but was >5 mg m^{-3} above the norm (Fig. 4). The evolution of the phytoplankton community composition at Halifax-2 in 2007 was similar to that seen previously, i.e. diatoms dominated in the winter/spring, i.e. >75% of the total count, and flagellates and dinoflagellates dominated (>60% of the total count) the rest of the year. However, the contribution of diatoms to the microplankton community immediately following the spring bloom was lower (~10%) and the contribution of flagellates higher (~80%) than normally seen. Overall, diatoms account for ~45% of the total community counts, flagellates account for another ~40% and dinoflagellates for ~10%.

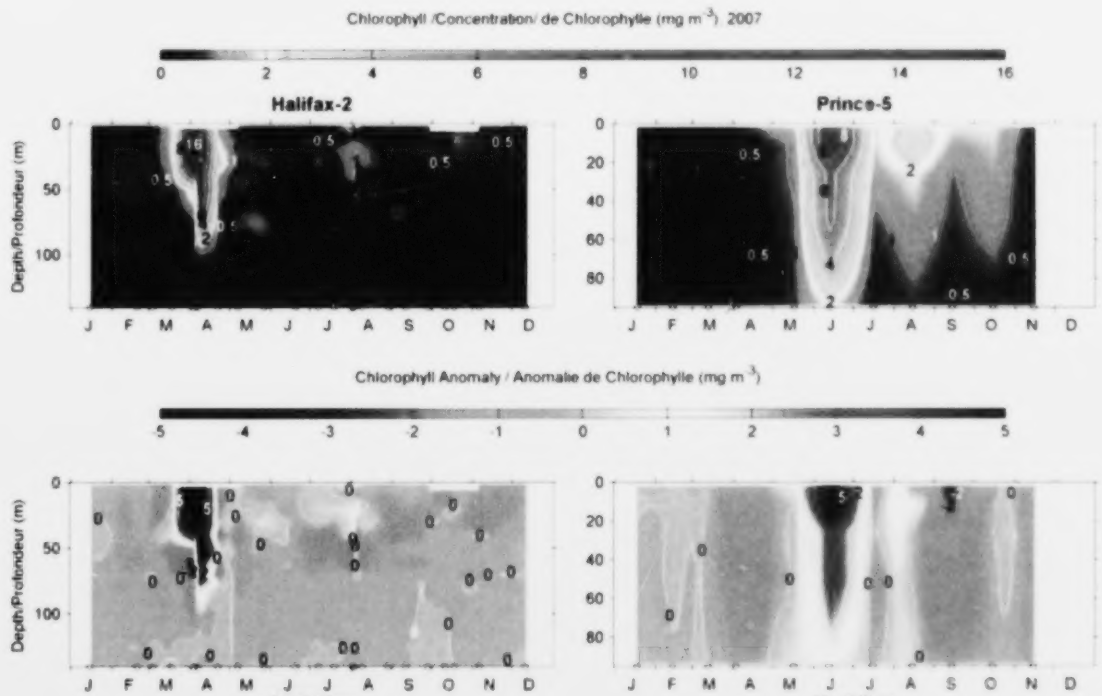

Figure 4. Vertical chlorophyll structure and chlorophyll anomalies (2007 minus long-term mean) at the AZMP-Maritimes fixed stations in 2007.

The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2; is characterized by a primary burst of growth in summer (June) with secondary peaks in late summer or fall (August-

the shelf (e.g. Emerald Basin) and in slope waters off the shelf edge. Bottom water oxygen saturation on the Scotian Shelf in summer 2007 (Avg: 77% sat) in contrast, was similar to the long-term average (79% sat). Similarly, the area of the bottom covered by waters with <60% saturation was the same as the long term average (10,600 km^2 or ~11% of the shelf area). Lowest saturations were found in deep basins (e.g. Emerald Basin) and deep waters off the shelf edge where nutrients are highest.

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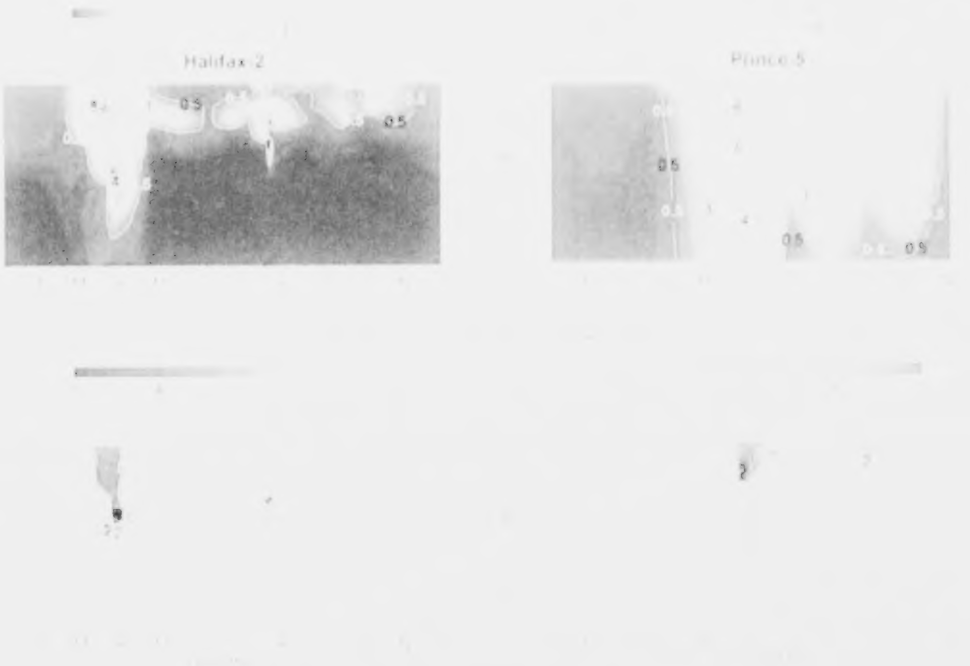

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The phytoplankton growth cycle at Prince-5, in contrast to Halifax-2, is characterized by a primary burst of growth in summer (June) with secondary peaks in late summer or fall (August

September) (figs. 4 and 5). In 2007, the peak concentration (600 mg m^{-2}), occurring on YD 164, was significantly higher than the long term average (400 mg m^{-2}) but normal in timing relative to the long term mean (Fig. 5). However, the duration of the primary bloom (96 days) was longer than the average (73 days). The anomaly plot confirms the timing of the primary peak was normal and the magnitude was >5 mg m^{-3} above average (Fig. 4). A negative anomaly (-2 mg m^{-2}) in September indicated a diminished secondary fall peak. As has been noted previously, the phytoplankton community at Prince-5 is comprised almost exclusively of diatoms (>95%), year-round. Total microplankton counts during the blooms at both fixed stations did not increase to the extent that chlorophyll levels would have suggested. On an annual basis, Prince-5 sustains the larger chlorophyll inventories of the two Maritimes fixed stations (P-5: >100 mg m^{-2}, Halifax-2: 75 mg m^{-2}) and a substantially longer production cycle.

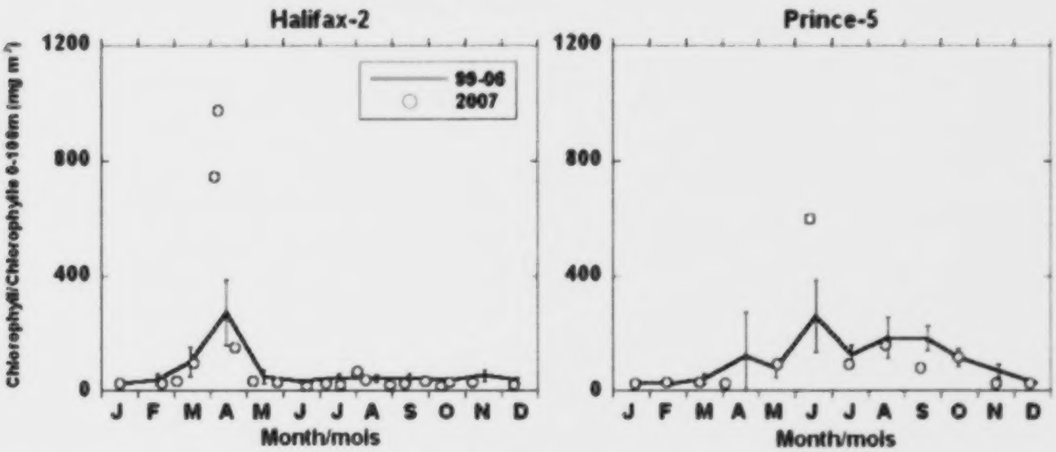


Figure 5. Chlorophyll inventories (surface to 100 m) at the AZMP-Maritimes fixed stations in 2007.

A more detailed analysis of the timing of the bloom at Halifax-2 revealed that the 2007 bloom started earlier (YD 77) than in 2006 (YD 90) and closer to the long term average, YD 71 (Fig. 6). The duration of the bloom was longer (35 days) than in the previous two years but shorter than the long-term average (46 days). In addition to changes in bloom dynamics, the "background" chlorophyll levels (outside the bloom period) have been declining over the past 9 years, from ~40 mg m^{-2} in 1999 to <30 mg m^{-2} in 2007. At Prince-5, the peak concentration (600 mg m^{-2}) occurred on YD 164 which was significantly higher than the long term average (400 mg m^{-2}) but normal in timing relative to the long term mean. However, the duration of the primary bloom (96 days) was longer than the average (73 days).

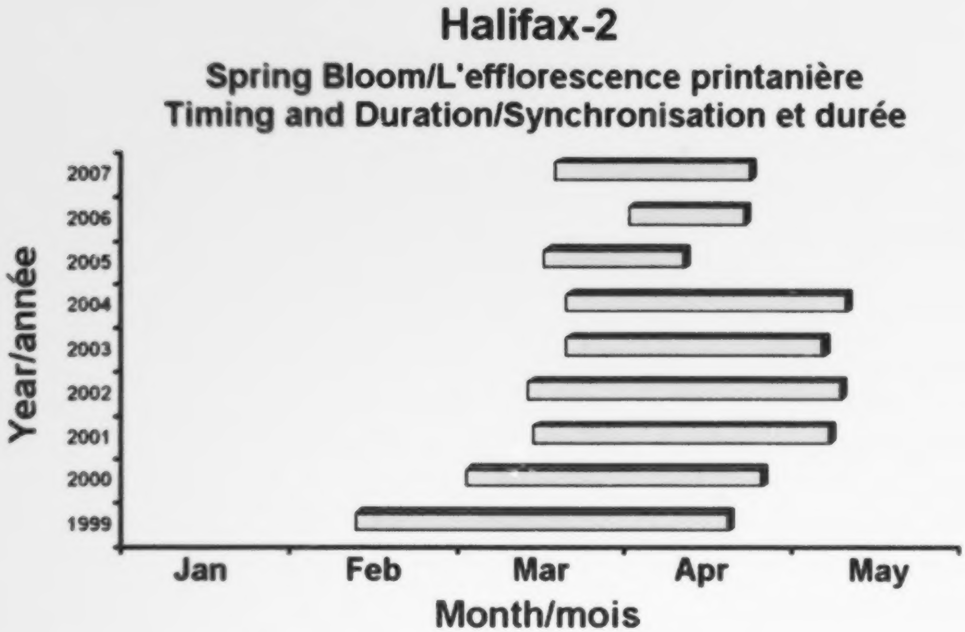


Figure 6. Duration (horizontal bars) and timing and duration of the spring phytoplankton bloom at the Halifax-2 fixed station, 1999-2007.

Shelf Sections: Chlorophyll levels along all the shelf sections are always considerably higher in spring than in fall. Chlorophyll levels during the spring of the 2007 survey were no exception and were, in fact, the highest observed since AZMP observations began in 1999 (Fig. 7), particularly along the Louisbourg, Halifax and Browns Bank lines. Concentrations exceeding 8 mg m^{-3} were seen as deep as 100 m. Indeed, chlorophyll inventories were at record high levels in spring, i.e. ~600-700 mg m^{-2} in 2007 versus the long-term average of ~150-300 mg m^{-2}. In contrast, chlorophyll levels during the fall surveys were at or slightly below (~30-40 mg m^{-2}) average levels (~30-50 mg m^{-2}).

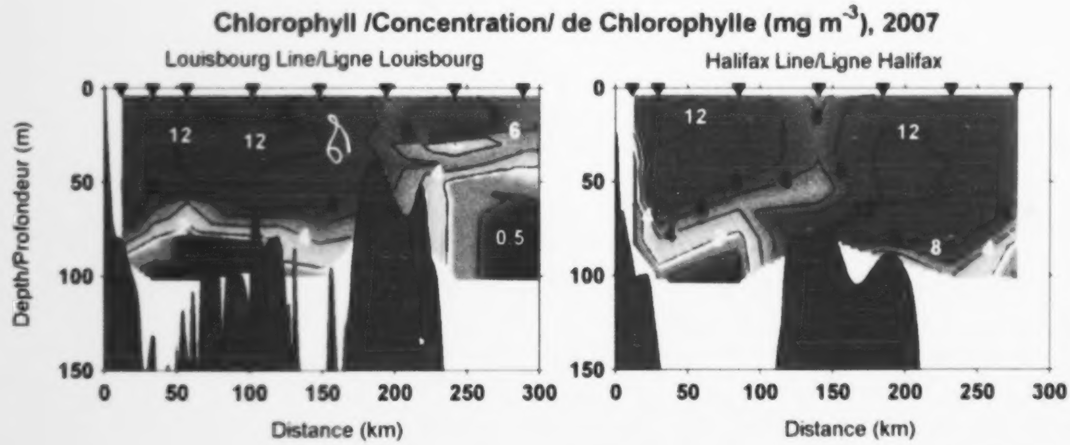
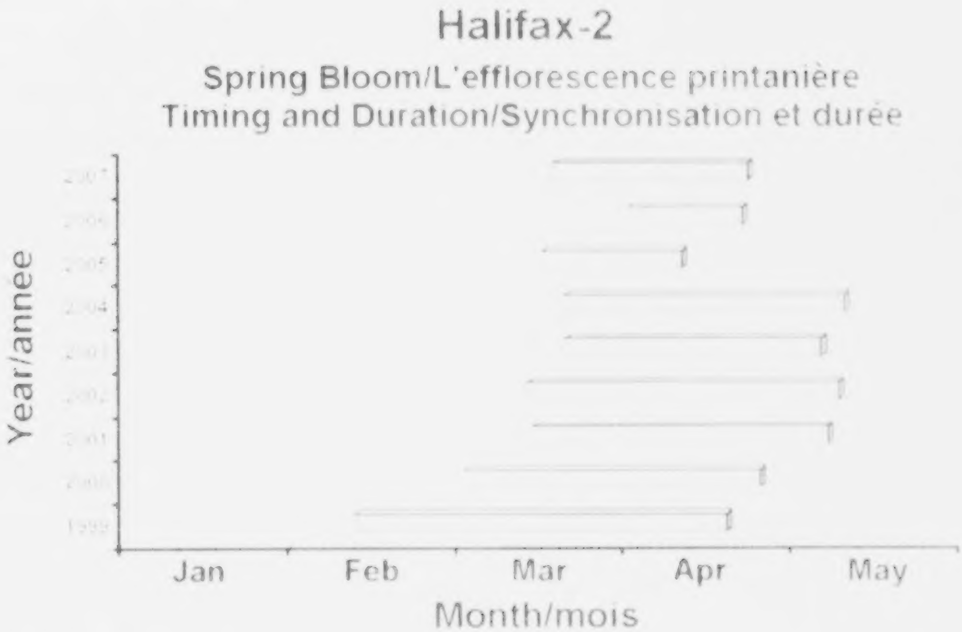


Figure 7. Vertical chlorophyll structure along the Louisbourg Shelf and Halifax sections in spring 2007.



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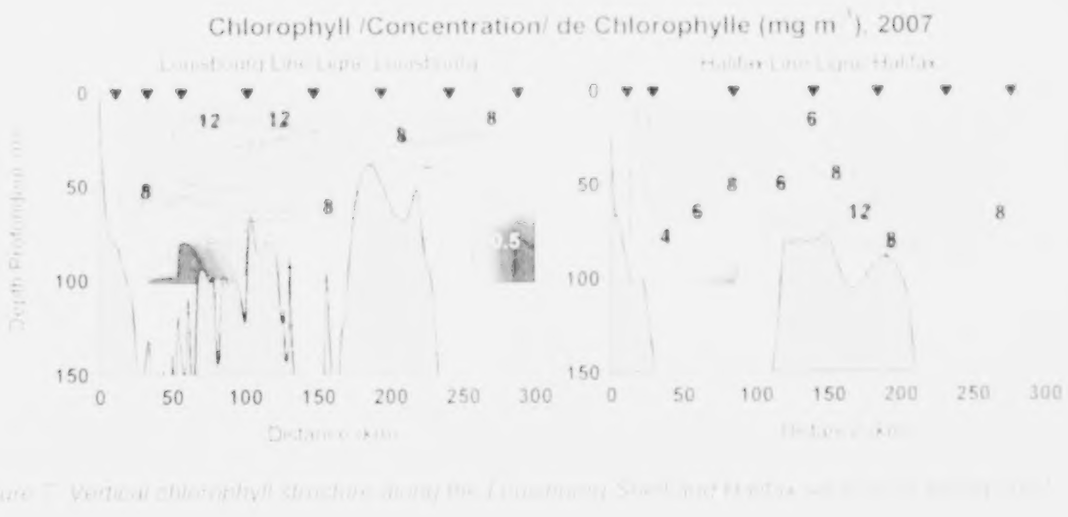

Figure 7. Vertical chlorophyll structure along the Louisbourg Shelf and Halifax sections in spring 2007.

Trawl (groundfish) Surveys: Near-surface chlorophyll levels during the 2007 spring survey (5-24 March) on the eastern Scotian Shelf showed a distributional pattern somewhat different from previous years, i.e. the high concentrations seen off-shelf (usually >8 mg m^{-3}) and distributed along the eastern sector were distributed more in the western sector and lower in concentration, mostly in the 2-6 mg m^{-3} range. Surface chlorophyll levels during the summer Scotian Shelf survey (2 July – 2 August), on the other hand, were uniformly low (<1 mg m^{-3}) over the central and eastern shelf. Elevated concentrations (>1 mg m^{-3}) were only observed near the coast off SW Nova Scotia and approaches to the Bay of Fundy, as observed in previous years. These areas are generally characterized by strong vertical mixing. Overall, summer surface chlorophyll concentrations on the Scotian Shelf in 2007 were the same as the long-term average of 0.68 mg m^{-3}.

Satellite Remote-Sensing: Satellite ocean colour (SeaWiFS and MODIS) data provide a valuable alternative means of assessing surface phytoplankton biomass (chlorophyll) at the AZMP fixed stations, along the seasonal sections, and at larger scales (Northwest Atlantic) and have the potential to provide temporal data and synoptic spatial coverage not possible from conventional sampling. Composite images of the Maritimes region covering the major periods of the shelf section surveys and trawl surveys put those operations into a larger geographic context and reveal features that supplement/corroborate ship-based observations or provide information not otherwise attainable. For example, the off-shelf maximum in surface chlorophyll generally observed during the early March Eastern Scotian Shelf trawl survey was absent for the most part in 2007 based on MODIS imagery. In a similar way, the MODIS imagery indicated clearly the intense, wide-spread and persistent, longer duration (eastern shelf) spring bloom that occurred on the Scotian Shelf in April, 2007 (Fig. 8). As well, images show the overall low surface chlorophyll levels observed during the July trawl survey and elevated eastern shelf surface chlorophyll levels seen during the October shelf section survey.

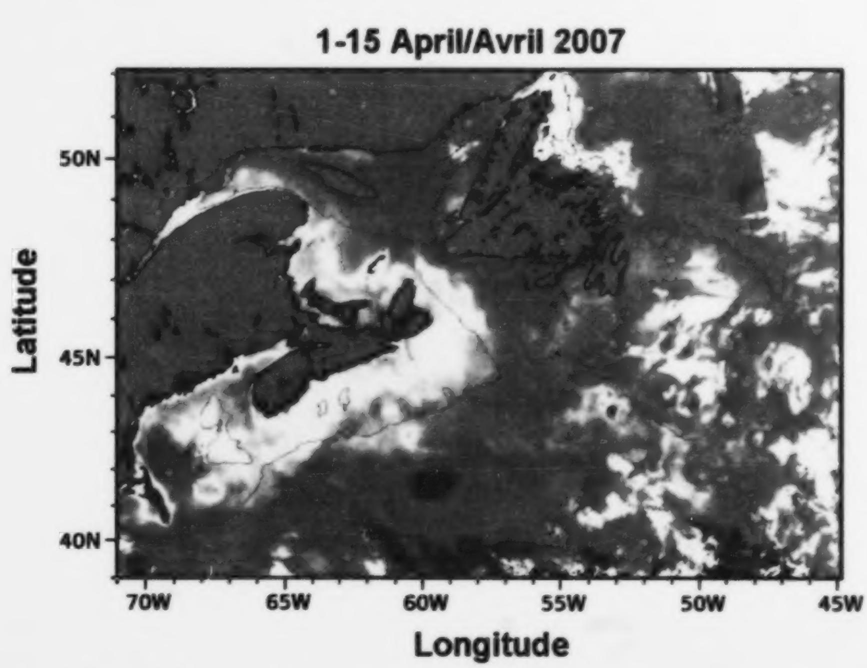

Figure 8. Surface chlorophyll concentrations in the Maritime region during the spring bloom in April, 2007 from the MODIS ocean colour satellite sensor.

An equally informative application of the satellite-based chlorophyll fields is to generate graphical representations of the seasonal chlorophyll dynamics along the shelf sections. It is evident from the satellite-data, for example, that surface chlorophyll concentrations are generally higher on the eastern Scotian Shelf than on the central and western shelf; spring levels along all lines were particularly high in 2007. The dynamics of the onset, duration and termination of the spring and fall blooms are also revealed in this type of graphical presentation as well as spatial (across-shelf) relationships. For example, it is apparent that the duration of the spring bloom in 2007 was longer on the Eastern Shelf and in Cabot Strait than seen previously (Fig. 9). The bloom duration was also longer in 2006 in the east, however, its magnitude was not nearly as high as seen in 2007. Generally speaking, spring blooms on the Scotian Shelf can be viewed as discrete, intense and short-lived events whereas the fall blooms appear to be much weaker in magnitude, more diffuse and time-varying.

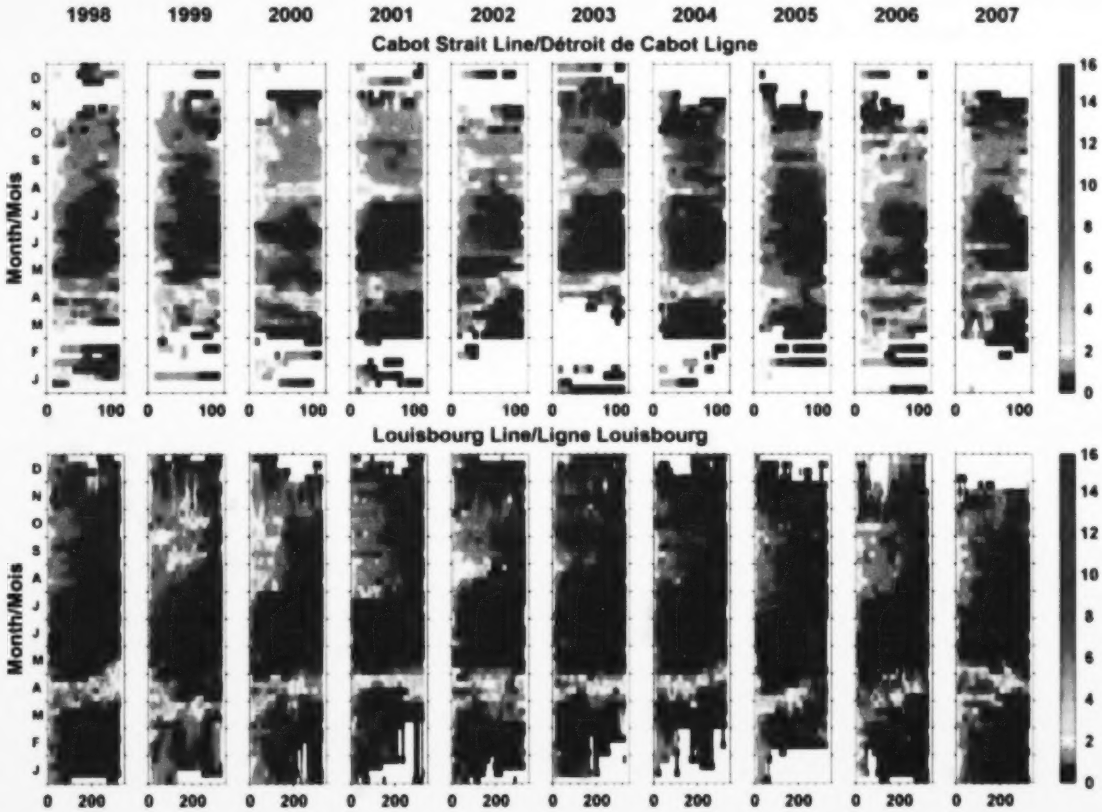

Figure 9. Surface chlorophyll concentrations (1999-2007) along the Cabot Strait and Louisbourg shelf sections from the SeaWiFS ocean colour satellite sensor.

At the larger scale, the timing and duration of the spring bloom in 2007 compared with previous years in most regions. The exceptions were Cabot Strait where the bloom was approximately a week later than usual and the Cabot and Louisbourg lines where high concentrations lasted longer than usual. Most notable, however, was the fact that the magnitude of the 2007 bloom was at record high levels at all locations on the Scotian Shelf; peak surface chlorophyll concentrations 2-6x higher than average conditions (over previous 9 years) were observed. In the western Gulf of Maine (Lurcher Shoal and Georges Bank) and Bay of Fundy, however, levels in 2007 were comparable to the long term mean.

Continuous Plankton Recorder (CPR): The CPR is the longest data record available on plankton in the Northwest Atlantic, starting in 1961. CPR data analysis lags AZMP reporting by one year; thus, only data up to 2006 are currently available. Nonetheless, the phytoplankton colour index and abundance of large diatoms and dinoflagellates on the Scotian Shelf (57°-66°W) have been notably higher, starting in the early 1990s, peaking in the mid 1990s and continuing into the 2000s, than levels observed in the 1960s-1970s. On the shorter time scale, the phytoplankton colour index on the Scotian Shelf has been declining over the past few years with levels approaching the long-term average. Diatoms and dinoflagellates declined as well in 2006 but remain close to the long-term average.

Zooplankton

Fixed stations: Zooplankton biomass and abundance were low in 2007, but there were near-record peaks in zooplankton biomass and *C. finmarchicus* abundance at Halifax-2. Average zooplankton biomass over the year was close to normal in 2007 at Halifax-2, but the biomass peak in April and May was higher than normal (Fig. 10). Biomass at Halifax-2 was low prior to the bloom in February and March, and it was on the low side of normal in the summer and fall. At Prince-5, the zooplankton biomass was lower than normal overall, especially in the late summer and fall.

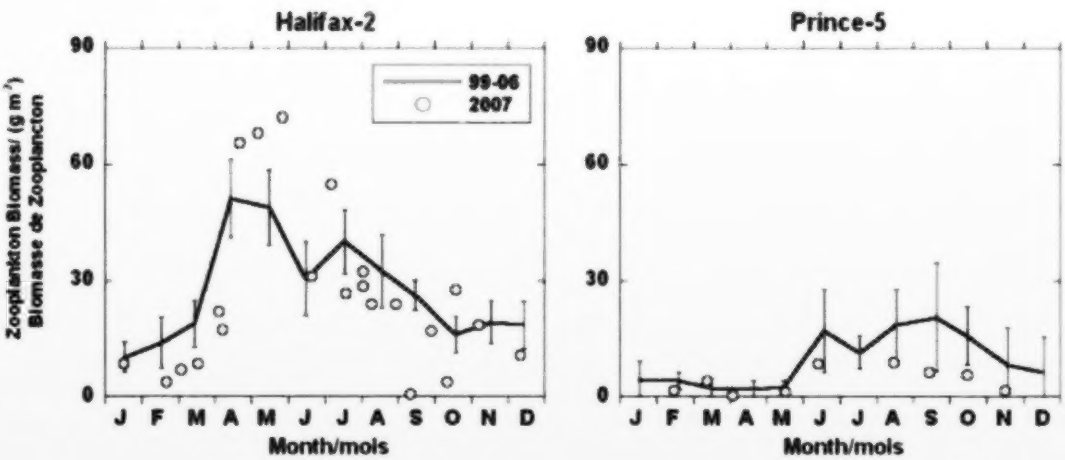

Figure 10. Zooplankton biomass at the AZMP-Maritimes fixed stations in 2007.

Calanus finmarchicus abundance followed a similar trend as total abundance at both Halifax-2 and Prince-5 (Fig. 11). However, the pre-bloom period of low abundance at Halifax-2 lasted longer for *C. finmarchicus* than for zooplankton abundance overall, remaining low into April. The abundance peak for *C. finmarchicus* was later and shorter than normal, and it was the second highest since the time series began in 1999 (Fig. 12). The seasonal development of the *C. finmarchicus* population structure was similar to past years. The proportion of adults in the CI – CVI population began to increase in December, 2006, and continued to increase until the end of February, when the proportion of early copepodid stages had begun to increase. Early copepodid stages dominated before the abundance peak, and later copepodid stages dominated after the peak, with a subsequent shift to dominance of CV stages indicating that the population began to go into dormancy by late July, about a month later than normal. A second peak of early copepodid stages in September indicates that part of the population remained active into the fall.

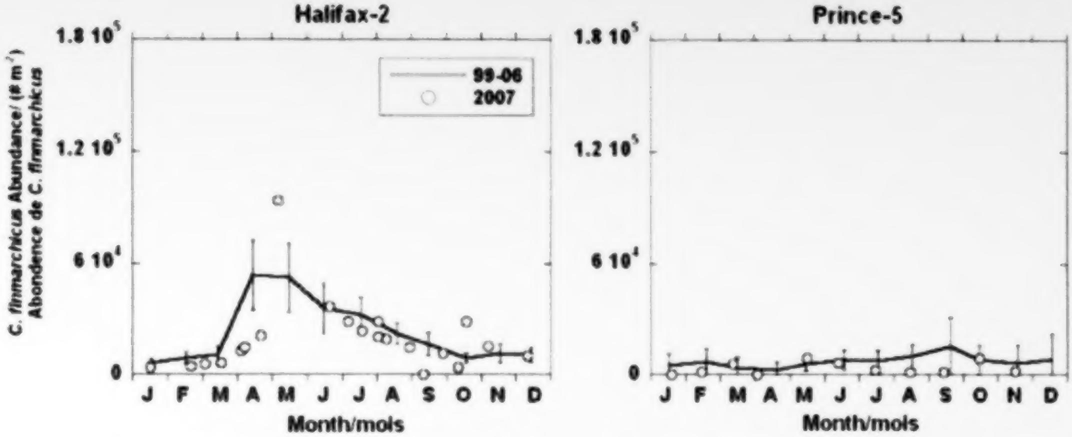

Figure 11. Calanus finmarchicus abundance at the AZMP-Maritimes fixed stations in 2007.

At Prince-5, the average *C. finmarchicus* biomass over the year was lower than normal, especially in the late summer to early fall (Fig. 11). Despite their low abundance, the *C. finmarchicus* population structure at Prince-5 was similar to previous years, as well as to that at Halifax-2 during the first part of the year. Emergence from dormancy began in December, and early stage contribution to the population increased at the end of March, slightly later than at Halifax-2. By July, the population began to be dominated by CVs, but this trend was reversed during the fall when the proportion of CI to CIII stages increased and dominated the population.

Zooplankton abundance at Halifax-2 was lower than normal throughout 2007, especially in late winter and in the summer and fall (Fig. 13). The 2007 zooplankton abundance peak at Halifax-2 was a few weeks later than normal, similar to the biomass peak. The contrast between the above-average biomass peak and below-average abundance peak is probably due to the high peak abundance of *Calanus finmarchicus*, a large-bodied copepod that is a biomass-dominant species on the Scotian Shelf and in the Gulf of Maine. Lower-than-normal abundances of two numerically dominant copepods, *Oithona similis* and *Pseudocalanus* spp. contributed to the low overall zooplankton abundance at Halifax-2 in 2007.

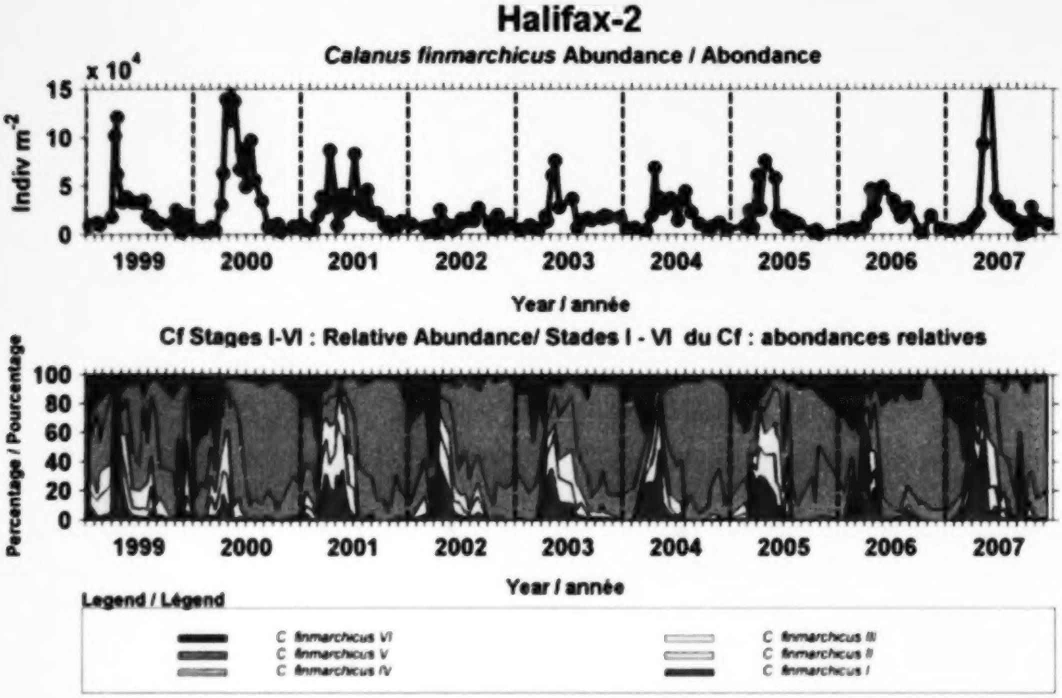

Figure 12. Time-series (1999-2007) of Calanus finmarchicus abundance and developmental stages at the Halifax-2 fixed station.

Several warm-water species that are normally abundant in the summer-fall period, including *Temora longicornis*, *Paracalanus* spp., and *Centropages typicus*, were nearly absent at Halifax-2 in 2007 (Fig. 13). *Oithona atlantica*, bivalve larvae, and euphausiids, normally present during the spring-summer period, were also rare in 2007 at Halifax-2, but three Arctic copepods, *Calanus hyperboreus*, *C. glacialis*, and *Microcalanus* spp., and the deep-water copepod *Metridia lucens* were present at near-normal abundance levels.

At Prince-5, species that are normally dominant were not abundant, while cladocerans were seen in larger numbers than previously observed. At Prince-5, the abundance peaks in 2007 were later than normal, in August and October, and the second peak was much lower than normal (Fig. 13). The community changes at Prince 5 in 2007 were more extreme than the changes observed at Halifax-2. Like *Calanus finmarchicus*, the abundance of the taxa that are normally dominant, *Oithona similis*, *Pseudocalanus* spp., and euphausiids, were low, and *Temora longicornis*, *Paracalanus* spp., and bivalve larvae were nearly absent. The abundance of the summer-fall copepod *Centropages typicus* was also low, but *Centropages* spp., representing younger stages that are not identified to species, was more abundant than normal. Despite the low abundances of many taxa, the overall zooplankton abundance peak in 2007 was similar to previous years, due to high abundance levels of the cladocerans *Evadne* and *Podon*. The dominance of these cladocerans have not previously been observed at Prince-5.

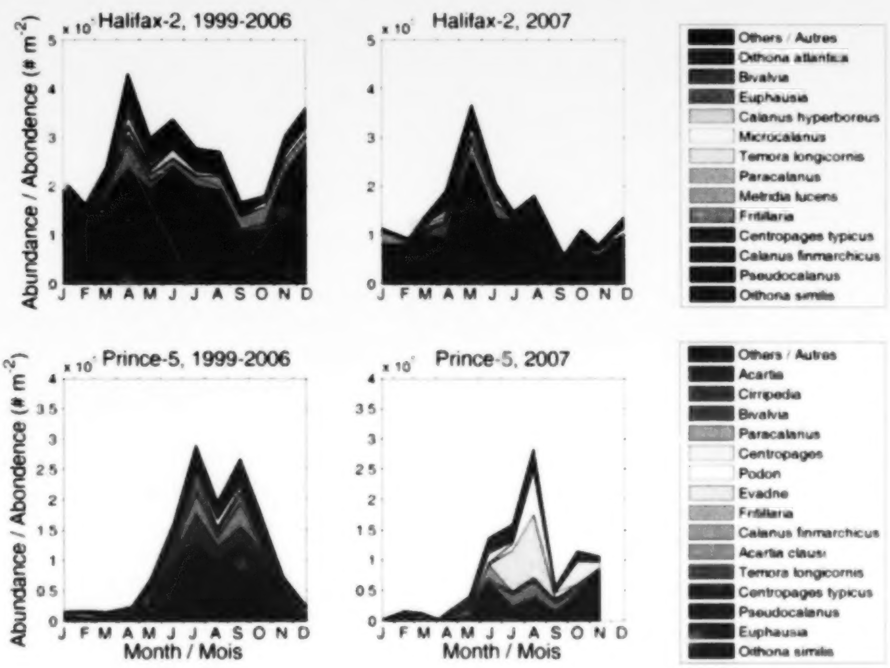

Figure 13. Seasonal variability of dominant taxa at Halifax-2 and Prince-5. The top 90% of taxa by abundance are shown individually; other taxa are grouped as 'others.' Left-hand panels are based on average abundance of monthly mean abundance from 1999-2006. Right-hand panels are monthly mean abundance in 2007.

<u>Shelf Sections</u>. On all sections, *Calanus finmarchicus* populations are dominated by CV and some CIV stages in the fall and by young copepodid stages in the spring (data not shown). Seasonal biomass variability of *C. finmarchicus* was out of phase between the Cabot Strait line in the east and the Halifax and Brown's Bank lines in the west. This difference in seasonal biomass variability may be due to the suitability of habitat in the two areas for different life history phases, i.e. dormancy v. active development, of *C. finmarchicus*. The Louisbourg line, where *C. finmarchicus* does not exhibit clear seasonal cycles, may be influenced to varying degrees by both of these environments. Springtime *C. finmarchicus* biomass in 2007 was the lowest yet observed on both the Halifax and Brown's Bank lines, and it was also low on the Louisbourg and Cabot Strait lines. Fall *C. finmarchicus* biomass in 2007 was the highest yet observed on the Cabot Strait line.

The abundance of zooplankton was slightly lower than normal in spring 2007 at most of the transect stations. A core group of three numerically dominant copepod species, including *Oithona similis, Calanus finmarchicus*, *Pseudocalanus* spp., was found at nearly all transect stations, similar to normal conditions, and the larvacean *Fritillaria* spp. was found at nearly all of the stations on the shelf lines, also similar to normal conditions. The off-shore shelf stations exhibit slightly elevated proportions of rare species and of the copepod *Oithona atlantica* in spring, reflecting the influence of the high-diversity, warm water, offshore zooplankton community at these stations. In spring of 2007, the contributions of *Oithona atlantica* and rare species were lower than normal on the two southern lines. The Arctic species *Calanus hyperboreus* and *C. glacialis* made up a larger proportion of the community than normal in spring of 2007, especially on the Louisbourg and Cabot Strait lines. *Centropages* spp. made up a slightly higher than normal proportion of the zooplankton community on the Browns Bank and Halifax lines in spring 2007.

Fall zooplankton abundance in 2007 was lower than normal across the central and eastern Cabot Strait stations and at the inshore and mid-shelf stations on the Scotian Shelf, especially on the Browns Bank line. Zooplankton abundance was closer to normal at the offshore stations on the Louisbourg, Halifax, and Brown's Bank lines. In the fall, *Oithona similis*, *Paracalanus*, *Centropages typicus*, and *Calanus finmarchicus* are numerically dominant species on the mid-shelf, while *O. similis*, *C. finmarchicus*, and *Temora longicornis* are dominant in Cabot Strait. In fall 2007, however, the proportion of *C. typicus* was much lower than normal on all the lines, and *Paracalanus* spp. also represented a lower than normal proportion of the community on the Louisbourg and Cabot Strait lines. On the Cabot Strait line in fall 2007, *C. hyperboreus* and *Metridia lucens* exhibited higher relative abundances than normal. In the fall, the offshore community becomes more prominent at the off-shore shelf stations than in the spring, represented by the copepods *Mecynocera clausi*, *Clausocalanus* spp., the ostracod *Conchoecia* spp., and rare taxa. In fall 2007, the offshore community on the Halifax line was less prominent on the mid-shelf, and *Mecynocera clausi* was a smaller proportion of the offshore community. On the Louisbourg line, encroachment of the offshore community onto the shelf was about normal, while on the Brown's Bank line, it was greater than normal.

Trawl (groundfish) Surveys. The zooplankton biomass distribution in 2007 generally followed the normal pattern of higher biomass in deep waters, including deep basins, channels, and the shelf edge. In 2007, the survey-wide average zooplankton biomass in February was the lowest yet observed since the beginning of the survey in 1999. Zooplankton biomass on the eastern Scotian Shelf in March continued the trend of low abundance started in 2005, but it was not as low as in 2006. Zooplankton biomass was also below average during the July Scotian Shelf survey, but *Calanus finmarchicus* abundance was close to normal.

Continuous Plankton Recorder (CPR): On the Scotian Shelf, the annual average abundance of *Calanus finmarchicus* early copepodid stages (1-4) in 2006 was close to the long-term average abundance. *C. finmarchicus* stage C5-6 abundance was above average, continuing a recent trend. *Paracalanus / Pseudocalanus* spp. annual average abundance was below the long-term average in 2006, down from average values in 2005, and total euphausiids returned to above average abundance after two years of below-average abundance.

Zonal Summary

To provide a summary among variables for the entire Atlantic Zone, we summarize the data are displayed as differences (anomalies) relative to 1999-2006 average values; furthermore, because these series have different units, each anomaly time series is normalized by dividing by its standard deviation (SD), which is also calculated using data from 1999-2006 (Figure 6).

Spring through fall nutrient inventories on the Newfoundland-Labrador and Grand Banks Shelf were above the 1999-2006 average, whereas nutrient inventories were generally below normal throughout much of the Gulf of St. Lawrence and the Scotian Shelf. However, winter maximum nutrients inventories (0-50 m) were above normal at all coastal fixed stations as well as in many areas of the Gulf of St. Lawrence (not shown). Phytoplankton demonstrated considerable spatial variability, with below average indices of abundance on the Newfoundland-Labrador Shelf and at coastal fixed sites off Halifax and in the Bay of Fundy, and above average indices of abundance throughout the western and southern Gulf of St. Lawrence as well as on the Scotian Shelf. Trends in average zooplankton abundance indices showed the greatest spatial coherence. Zooplankton abundance was well above average in the Gulf of St. Lawrence and to a lesser degree on the Newfoundland-Labrador Shelf whereas abundance was well below

average from Cabot Strait, across the Scotian Shelf and into the Bay of Fundy, and only slightly below average on the Grand Banks.

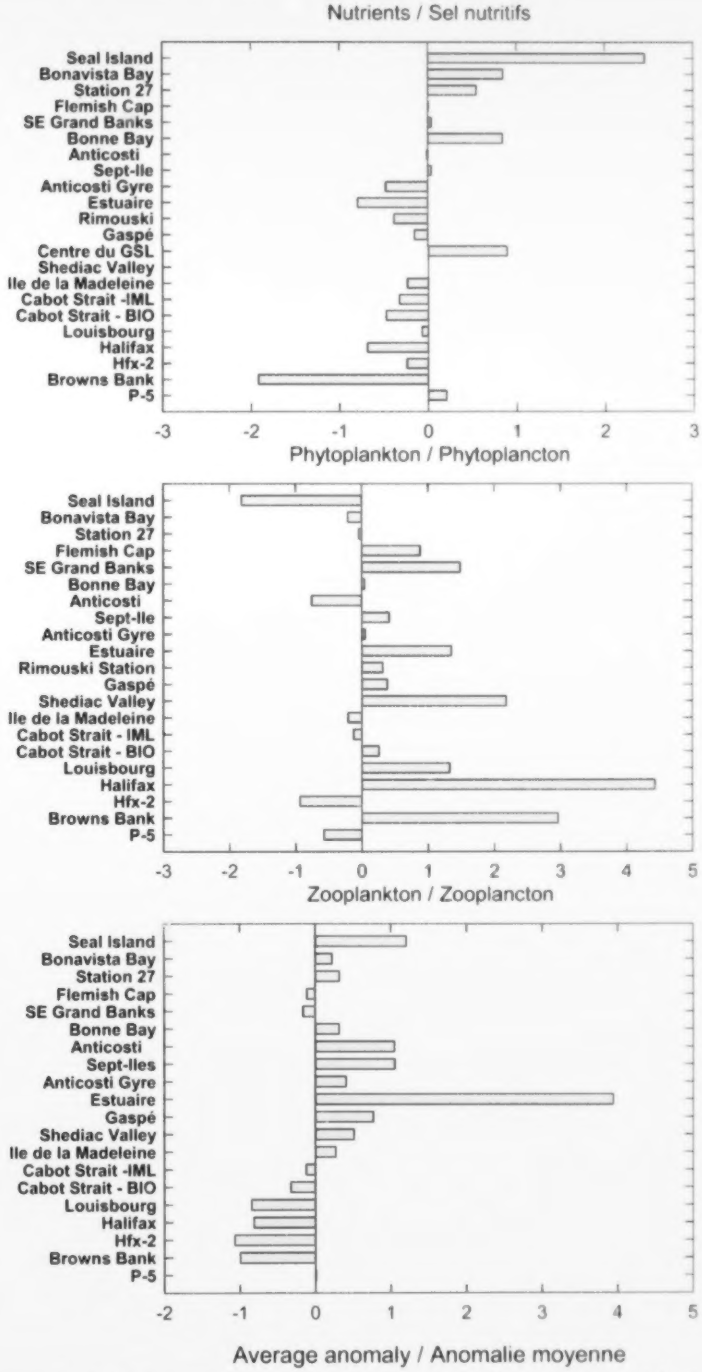

Figure 6. Zonal summary of the average anomaly of abundance indices for nutrients, phytoplankton and zooplankton for 2007.

Sources of Uncertainties

The general patterns in the spatial distribution of physical, chemical and biological oceanographic variables in the Northwest Atlantic zone monitored by AZMP has remained relatively constant during the period 1999-2005. Although there are seasonal variations in the distribution of water masses, plants and animals, these variations show generally predictable patterns. However, there is considerable uncertainty in estimates of overall abundance of phytoplankton and zooplankton. This uncertainty is caused in part by the life cycle of the animals, their patchy distribution in space, and by the limited coverage of the region by the monitoring program.

Physical (temperature, salinity) and chemical (nutrients) oceanographic variables are effectively sampled because they exhibit fairly conservative properties that are unlikely to show precipitous changes from year-to-year. Also, measurements of these variables are made with a good degree of precision. The only exception occurs in surface waters where rapid changes in the abundance of phytoplankton, particularly during the spring bloom, can cause rapid depletion of nutrients. In an attempt to be conservative in our description of the long-term changes in chemical variables, we restrict our conclusions to deep water inventories of nutrients.

The greatest source of uncertainty comes in our estimates of phytoplankton abundance because of the difficulties in describing the inter-annual variations in the timing, magnitude and duration of the spring phytoplankton bloom. Phytoplankton may undergo rapid changes in abundance, on time scales of days to weeks. Because our sampling is limited in time, and occasionally suffers from gaps in temporal coverage due to vessel unavailability or weather, which often occurs in the sampling at our fixed stations during the winter months, we may not sample the spring phytoplankton and other important variables adequately. Also, variations in the timing of the spring phytoplankton bloom across the region and in relation to our spring oceanographic surveys may limit our ability to determine inter-annual variations in maximum phytoplankton abundance. In contrast, we are better capable of describing inter-annual variations in the abundance of dominant zooplankton species because their seasonal cycle occurs at time scales of weeks to months because of their longer generation times. However, zooplankton show greater variability in their spatial distribution. Although inter-annual variations in the abundance of dominant groups, such as copepods, can be adequately assessed, variations in the abundance of rare, patchily distributed or ephemeral species cannot be reliably estimated at this time.

In the Maritimes/Gulf regions, seasonal sampling at the Shediac Valley fixed-station in the Southern Gulf has been significantly impacted by unavailability of ship-time; only 4-6 of the target ~15 sampling dates have been achieved for the past 3-4 years. Another important data gap exists for the Canadian portion of the Gulf of Maine and Georges Bank. This significant geographic component of the Maritimes Region is not systematically sampled by AZMP, except for some modest sampling during the February and July trawl surveys and satellite coverage, and thus seasonal to inter-annual variations of key variables are not available for this area. With regard to ecosystem components, macrozooplankton particularly krill, are not systematically sampled in the Maritimes/Gulf regions, except by CPR, and therefore quantitative estimates of biomass, abundance and inter-annual variability are not available.

CONCLUSION AND ADVICE

The spring phytoplankton bloom in the Maritimes region was the strongest and most widespread seen since systematic observations began in 1999. Winter inventories of nutrients were not sufficient to account for this remarkable growth so some additional source of nutrients, yet to be

identified (perhaps large-scale advection of Labrador Slope Water from offshore), must have fuelled the bloom. Despite the record high levels of chlorophyll during the bloom, phytoplankton biomass the remainder of the year continued to decline in 2007, the decline possibly being linked to lower than normal summer surface nutrient inventories linked to reduced mixing.

Zooplankton biomass and abundance were lower than normal during most of 2007, but the 2007 zooplankton biomass peak was unusually high, driven by high abundance of the copepod *Calanus finmarchicus*. This large peak may have been related to high *C. finmarchicus* egg production during the unusually large phytoplankton bloom that occurred about a month before the zooplankton peak. Warm-water zooplankton taxa that are usually abundant during summer and fall were less abundant than normal on the Scotian Shelf, and Arctic species made up a larger proportion of the community than normal on the eastern Scotian Shelf. This shift in zooplankton community composition was likely related to low temperatures in both surface and deep waters of the Scotian Shelf.

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